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PREPRINT

NEUTRAL ATMOSPHERE COMPOSITION MEASUREMENT BETWEEN 133 AND 533 KILOMETERS FROM THE GEOPROBE ROCKET MASS SPECTROMETER

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JUNE 1969

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OUTLINE

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ABSTRACT

The number densities of He, N_2, O_2, and O in the altitude range from 133 to 533 km were determined by a magnetic mass spectrometer on a Javelin rocket (Geoprobe) from Wallops Island, Va., at 12 hr. 59 min. 42 sec. E.S.T. March 2, 1966. The instrument was under vacuum when launched and exposed to the ambient atmosphere by means of a pyrotechnique break-off device. The ion source was enclosed in a chamber (silver oxide coated to inhance recombination of O into O_2) and samples the atmosphere through a knife-edged orifice. The He and N_2 concentrations agree well with the CIRA 1965 model above 250 km, while the model values of O and O_2 densities in the lower thermosphere are higher than the measured values. Integration of the N_2 altitude profile indicates an exospheric temperature of approximately 900°K during the flight. The O/O_2 ratio was 10 at 210 km and the O/N_2 ratio was 1 at 265 km (1.52×10^8 cm^{-3}). He and N_2 were equally abundant at 300 km with a number density of 5.5×10^6 cm^{-3}. The atomic oxygen concentrations measured represent a lower limit to the ambient abundance since no correction was made for probable losses due to surface adsorption within the ion source and chamber.

INTRODUCTION

The neutral composition of the thermosphere was measured by a mass spectrometer on a Geoprobe rocket (Argo D-4 Javelin, NASA 8.25) launched March 2, 1966, at 12 hr. 59 min. 42 sec. E.S.T. from Wallops Island, Virginia. The mass spectrometer was located perpendicular to the spin axis of the payload (Fig. 1) and employed an enclosed ion source exposed to the atmosphere through a knife-edged orifice (Figs. 2 and 3). The interior surfaces of the chamber and ion source were chemically prepared to enhance the recombination of atomic oxygen. [1] The spectrometer was under vacuum when launched and exposed to the ambient atmosphere by means of a pyrotechnic breakoff device (Fig. 3). The orificed chamber permits determination of the atmospheric constituent number densities using the well-known thermal transpiration relationship, modified by a factor $F(s)$ which relates on the ratio of the instrument velocity to particle velocity.[2]

The FPS-16 radar was used to determine the trajectory parameters and an on-board solar aspect sensor and magnetometer provided the payload orientation throughout the flight. Some pertinent vehicle information is shown below:

Apogee = 630 km
horizontal range = 847 km
latitude = 38°N to 37°N
longitude = 75°W to 66°W
spin period = 0.80 sec.
precession period = 10.55 sec.
precession cone half angle = 11.5°

The flight data indicate that the mass spectrometer was exposed to a large deluge of gas when the breakoff device was actuated (122.5 sec. after launch at 175 km altitude). This situation was evident from large signals on the 28, 14, 32, 16, and 18 ion collector buckets on the upleg portion of the flight. As the flight progressed, the sensor was "pumped out" by the low ambient pressure and usable data were obtained on the downleg (Fig. 4) between 533 km and 133 km. Data for N_2, He, O, and O_2 were obtained and are reported here. There were a total of 14 data points for molecular nitrogen, 9 for helium, 11 for atomic oxygen, and 4 for molecular oxygen.

The purpose of this paper is to present these data, relate them to other experimental data obtained in the same altitude region, and discuss their possible implications for physical processes taking place in the thermosphere.

EXPERIMENT

The neutral particle mass spectrometer used on this flight was a double-focusing magnetic deflection instrument (Fig. 5) similar to the experiments on Explorers 17 and 32 satellites.[3,6] The Explorer 17 experiment employed a relatively open ion source while the Geoprobe and Explorer 32 experiments utilized an enclosed (chambered) ion source, exposed to the atmosphere through a knife-edged orifice. The interior surfaces of the spectrometer ion source and chamber were coated with silver oxide (Ag_2O) to obtain a high rate of recombination of ambient atomic oxygen into molecular oxygen. This was done to enhance the determination of the absolute value of atomic oxygen number

densities at altitudes greater than 200 km (where the concentration of atomic oxygen greatly dominates that of molecular oxygen.)

As shown in Figure 5, the ambient neutral atoms and molecules are ionized by electron bombardment in the ion source. The resulting ions are accelerated into the magnetic field of the analyzer and separated, according to charge-to-mass ratio. The individual ion currents, proportional to the number densities of the corresponding neutral particles in the ion source, are collected on ion-cups located at pre-selected positions along the analyzer focal plane. Sampling is accomplished by stepping the input of an electrometer amplifier between the various collectors. The output of the electrometer is fed to a logarithmic amplifier and compressed into a voltage range compatible with the 0 to 5 volt telemetry system.

Figure 6 is a reproduction of a portion of the actual flight telemetry record showing one complete cycle of the logarithmic amplifier output taken at 228 kilometers altitude. The voltage stairstep levels at the beginning of the record are the in-flight calibration for the logarithmic amplifier. Following the calibration is the "rezero sample" mode. This operation minimizes the effect of d.c. drift on the amplifier zero level by sampling the output voltage at zero input current, inverting the polarity, and inserting the voltage into the electrometer feedback loop. The amplifier zero position appears immediately after the sample mode, followed by the various ion currents monitored on this flight. The sequence of ion current sampling is helium (4), atomic nitrogen (14), water vapor (18), molecular oxygen (32), molecular nitrogen (28), and atomic oxygen (16). The low and high values refer to the two sensitivity ranges (differing by a factor of 100) of the electrometer

amplifier. The modulation observed on the telemetry record is produced by the high vehicle velocity (relative to the thermal velocity of the gas) causing alternate ram and rarefaction as the vehicle rotates. The dwell time on one mass and sensitivity was 2 seconds, the cycle time was 27 seconds, and the 10 second calibration occurred every 3rd cycle.

EXPERIMENT CALIBRATION

The instrument was calibrated on an ultra high vacuum system utilizing an oil diffusion pump with a cryosorb cold trap. The mass spectrometer sensor was mounted on the vacuum system as shown in Figure 7 and a comparison calibration performed with three commercial Veeco RG75 ionization pressure gauges. The ionization gauges had been calibrated against a McCleod absolute pressure gauge using the Florescen method of pressure reduction.[4] These gages have been used in the calibration of the omegatron and quadrupole mass spectrometers flown on the Thermosphere Probe rocket program[5] and the mass spectrometers flown on Explorer 32, thus minimizing relative calibration errors between these experiments.

The calibration procedure consisted of comparing the ion currents from the mass spectrometer and the pressure gauges over the pressure ranges from 10^{-9} torr to 10^{-6} torr. Initially the vacuum chamber was pumped to background pressure (mid 10^{-9} torr region), baked at 350°C for 12 hrs. and a background spectrum obtained with the mass spectrometer. A pure sample of gas (N_2, O_2, or He) was then introduced into the vacuum chamber in small increments through the leak valve and the readings of the pressure gauges and the mass spectrometer recorded simultaneously. The experiment could not be calibrated directly, however, for atomic oxygen; instead, the ratio of ionization cross sections of atomic

and molecular oxygen, determined by Fite and Brackman,[7] was used in conjunction with the calibration data for molecular oxygen. For the 75 ev electrons used in the ion source a sensitivity was obtained for atomic oxygen of 77% that of molecular oxygen; this ratio should have been maintained through the analyzer also, as it was operated in a 100% transmission mode. Interpretation of flight data included correction of m/e 16 (atomic oxygen) number densities for doubly ionized and dissociatively ionized molecular oxygen (formed by the ionizing electrom beam) which produced an ion current at mass 16 in the absence of neutral atomic oxygen in the ion source. Flight data exhibited a much higher 16/32 current ratio than the 0.197 observed during laboratory calibration. For each gas the mass spectrometer amplifier output was plotted against the average pressure from the three Veeco gauges. A typical sensitivity plot of spectrometer electrometer output (volts) vs. pressure (torr) is shown in Figure 8. A similar graph was generated for each of the calibration gases.

It is believed that the Veeco ionization pressure gauges used in the calibration of the spectrometer provided an absolute accuracy of ±3.25% at 2×10^{-6} torr to ±16% at 2×10^{-8} torr.

DATA ANALYSIS

The primary task of data analysis consisted of converting the telemetered electrometer output into number densities of the ambient atmospheric components. The number densities of the various gases in the ion source could readily be obtained from the ion currents, laboratory calibration data and instrument temperature (to convert pressure to number density).

Once the densities in the ion source chamber, Nc, were obtained as a function of time, the ambient densities for helium and moelcular nitrogen were calculated from the thermal transpiration equation modified for vehicle motion by the F(s) factor using the following equation:

$$N_a = \Delta Nc \left[\frac{T_i}{T_a}\right]^{1/2} \frac{1}{\Delta F(s)} \qquad (1)$$

where N_a = ambient number density

ΔN_c = difference between maximum and minimum chamber densities over a rocket spin cycle

T_i = chamber temperature

T_a = atmospheric temperature

$F(s) = \exp(-s^2) + s\sqrt{\pi}\,(1 + \text{erf}\, s)$

$$s = \frac{V_v \cos \alpha}{V_{PO}}$$

V_v = rocket velocity

α = angle-of-attack of sensor

V_{PO} = most probable velocity of ambient particles.

It can be seen in Figure 6 that there was a large modulated signal at mass 16, indicating a higher 16/32 ratio than was measured in the laboratory in pure molecular oxygen. Therefore, the ambient atomic oxygen number density was obtained by summing the ion source densities for masses 32 and 16 and applying an appropriate version of the thermal transpiration equation to each contribution. For mass 16 this took the form of equation (1); for mass 32,

equation (1) was multiplied by $\frac{2}{\sqrt{2}} = \sqrt{2}$ to (a) conserve mass in the calculation and, (b) account for the atomic flux into the chamber, and molecular flux out.

If the recombination of atomic oxygen is assumed to be constant during the flight (in particular, independent of atomic oxygen density or surface history) the ratio of recombined to unrecombined oxygen can be obtained at altitudes where there is no significant molecular oxygen. This ratio can then be applied at lower altitudes (where ambient O_2 is present) to distinguish ambient O_2 from recombined atomic oxygen. Thus,

$$\frac{N_c'(32)}{N_c(16)} = A \tag{2}$$

is determined at high altitudes, where $N_c'(32)$ is the number density (in the source) of recombined atomic oxygen and $N_c(16)$ is the number density of unrecombined atomic oxygen. At altitudes where ambient molecular oxygen becomes important, the total source density of O_2 consists of two components:

$$N_c(32)_T = N_c(32)_a + N_c'(32), \tag{3}$$

where $N_c(32)_T$ is the total source density of O_2 and $N_c(32)_a$ is the atmospheric contribution to the source density of O_2. Then

$$N_c(32)_a = N_c(32)_T - N_c'(32)$$

$$N_c(32)_a = N_c(32)_T - AN_c(16), \tag{4}$$

substituting from (2). The ambient molecular oxygen number density may then be determined as in equation (1).

MEASUREMENT ACCURACY

There are several sources of error present in the determination of the number density of an atmospheric constituent at a specific altitude. The major factors to be considered are pressure gage calibration accuracy, ion current detector and telemetry system accuracy, aspect system accuracy, and radar tracking accuracy.

The systematic error incurred through the pressure gages (Bayard-Alpert Veeco RG 75) used for calibration of the spectrometer is ±3.25% at 2×10^{-6} torr. The precision in reading ion currents through the electrometer amplifier logarithmic amplifier and telemetry is ±14%. The uncertainty in the angle-of-attack of the spectrometer orifice, as determined by the optical aspect systems, generates a ±7% uncertainty in the density determinations. The precision in the measurement of the ambient densities is thus better than ±16%. The radar tracking information obtained from the FPS-16 system produces less than ±0.5 km uncertainty in altitude determination. Due to the relative lack of knowledge concerning adsorption effects of atomic oxygen on the surfaces of the ion source and its enclosure, the number densities quoted for atomic oxygen can only be considered lower bounds to the true ambient density. On the other hand, the total oxygen density (as shown in Fig. 14), divided by $\sqrt{2}$, can be taken to be an upper bound to the ambient molecular oxygen (assuming no adsorption of the molecular species).

RESULTS

Molecular Nitrogen

The molecular nitrogen number density profile vs. altitude is shown in Figure 9, with the 1965 CIRA Model No. 2[12] for 1300 hrs (the most appropriate model for the solar and magnetic conditions at the time of the flight). The

circles refer to the N_2 obtained from the mass 14 and 28 ion current outputs during the downleg portion of the flight. It is assumed that there was no appreciable ambient atomic nitrogen measured; the smoothness of the N_2 profile using m/e 14 and 28 points tend to bear this out. A total of 14 data points are used to describe the N_2 profile and a smooth curve is drawn through the points. N_2 data from Hall et al. (1966),[6] Spencer et al. (1965),[5] Hedin, et al. (1965)[9] and Reber, et al. (1968)[6] are shown in Figure 10 for comparison. These data were chosen for comparison because of similar solar and geomagnetic indices; Table 1 gives a tabulation of some pertinent geophysical parameters for these various flights. The data obtained by Hall, et al., using a spectrometer designed to measure the atmospheric extinction of solar extreme ultraviolet radiation, was taken five minutes prior to the Geoprobe neutral density data. The N_2 data from the Geoprobe are also shown in Figure 11 along with the results from NASA 6.06 Thermosphere Probe N_2 data,[5] which are shown at 20 km intervals. Both sets of data were taken on the downleg portion of the flight with a smooth curve drawn thru the Geoprobe data. Although the two measurements were taken some four years apart, in the spring and fall, the three-hour geomagnetic index (ap) and 10.7 cm index of solar flux (F 10.7) are comparable.

Helium

The Geoprobe helium number density profile extending from 140 to 440 kms and the CIRA Model helium density are shown in Figure 12. Figure 13 shows helium data from other flights including Hedin and Nier (1965),[5] Hartmen, et al. (1966)[10] and Explorer 32 satellite mass spectrometer.[6]

TABLE 1

	NASA 8.25 Geoprobe	Hall, et.al.	NASA 18.01 Taevsch et.al.	NASA 6.06 Spencer et.al.	NASA 4.127AU Hedin and Nier	Hartman, et.al.	Exp. 32 Satellite
Date (day, month, year)	Mar. 2, '66	Mar. 2, '66	Mar. 19, '65	Nov. 20, '62	Apr. 15, '65	Dec. 12, '66	May 27, '66 thru May 30, '66
Local time of launch (hrs)	1300	1255	1309	1641	0345	0505 MET	1800 thru 1000
Ap six hours prior to taking data	0	0	6	4	2	32	2-4
F10.7 daily average, day prior to taking data ($w/m^2/c/s$)	81.2	81.2	74.3	89.0	75.8	75.3	109.4 105.6 – 103.2

Atomic and Molecular Oxygen

The atomic oxygen number density profile is shown in Figure 14 with the O and O_2 densities from the CIRA model for comparison. The O data were obtained by summing the atomic and molecular oxygen densities in the ion source and from these calculating the ambient atmospheric densities. The data have been corrected for doubly ionized and dissociatively ionized molecular oxygen. The O density profile has also been corrected at the lower altitudes by subtracting the ambient O_2 densities measured by the spectrometer. Figure 14 also includes atomic oxygen data from Hall, et. al. (1966)[8] and Hedin and Nier, (1965)[9] for comparison at the lower altitudes and Explorer 32 mass spectrometer data[6] for higher altitudes.

The molecular oxygen profile from the Geoprobe flight is shown in Figure 15, with the CIRA Model density. The four O_2 data points were obtained by subtracting the recombined atomic oxygen (see data analysis section) from the total 32 measured in the ion source and converting the difference to ambient O_2 atmospheric density, assuming that the recombination of O into O_2 was constant Also shown for comparison are Hedin and Nier (1965)[9] O_2 data.

Temperature

The neutral gas temperature calculated from the molecular nitrogen altitude profile is shown in Figure 16. Several boundary temperatures (T_1) were chosen at 450 km altitude and the temperatures integrated downward to 140 km. It can be noted that the scale height of the density profile and not the chosen T_1 value

at 450 km determines the temperature below approximately 200 km.[11] The temperature profile is given in Table 2 along with the altitude.

TABLE 2

Altitude (km)	Temperature (°K)	(km)	(°K)
133	405	240	895
140	517	250	891
150	647	260	889
160	728	270	896
170	774	280	908
180	802	290	900
190	826		
200	849		
210	871		
220	888		
230	896		

These data indicate an exospheric temperature near 900°K during the flight. Also shown in Figure 16 are the temperature profile obtained by Spencer, et.al. (NASA 6.06) from the Thermosphere Probe.

Mass Density Density and Mean Molecular Weight

The total mass density (ρ) obtained from the Geoprobe data is shown in Figure 17. These data cover the $\sum_i N_i m_i$ for N_2, He, O and O_2 over the altitude range 174 to 284 km. The model is higher than the measured data by a factor of 3.2 at the high r altitudes and 2.3 at 174 km, due to the lower concentrations of oxygen measured by the spectrometer. Also shown for comparison are the total density measurements from the Geoprobe pressure gages.[11] These data

agree between 175 and 210 km altitude, but diverge with increasing altitude. The disagreement in total density measurements between the mass spectrometer and pressure gages at the higher altitudes is consistent with the pressure gage interpretation by Pelz and Newton[11] stating that virtually all of the atmospheric atomic oxygen to which the gages were exposed was pumped or absorbed. Figure 17 shows the mean molecular weight

$$\left(\frac{\Sigma_i N_i M_i}{\Sigma_i N_i}\right)$$

vs. altitude for the Geoprobe, CIRA model, and Hedin et. al. (Apr. 1965).[9]

DISCUSSION

Molecular Nitrogen

The molecular nitrogen number density profile measured by the Geoprobe mass spectrometer agrees well with other measurements and theoretical model atmosphere values. The differences most likely reflect atmospheric variations and measurement uncertainties. NASA 18.01 and Hedin and Nier's data agree within 25% at the worst case but indicate a somewhat lower temperature. The Hall, et. al. data show a higher density by a factor of 1.5 but indicate the same scale height. If the Geoprobe data are extrapolated upward to the measurement region of the Explorer 32 mass spectrometer data, the agreement is within a factor of two. The Geoprobe mass spectrometer and NASA 6.06 omegatron N_2 data agree within experimental error over the altitude region of overlapping measurement. These correlations are in generally good agreement with the reaction of the atmosphere anticipated from solar flux and magnetic activity consideration (as predicted, for example, by the CIRA atmosphere).

Helium

The helium number density profile measured by the Geoprobe spectrometer agrees with the theoretical model within experimental error above 200 km but exhibits higher concentrations at the lower altitudes (150-200 km). The higher densities at the lower altitudes, when compared with the model, tend to agree with Hartman et. al. but show a quite different scale height. Although the absolute quantity measured is higher by a decade, the profile of the Geoprobe data agrees well with Hedin and Nier (1965) below 200 km. The Geoprobe He data and the other comparison profiles imply that helium is probably not in diffusive equilibrium below approximately 200 km. The possibility cannot be ruled out that the gas generation when the nosecone was released produced some species which adsorbed on the surface of the ion source and were subsequently disloged by other gases at lower altitudes; however this situation occurring at mass 4 is rather unlikely.

The Explorer 32 helium data [14] taken two months after the Geoprobe data indicate a lower value by a factor of 2.5 to 3. The increased helium concentration measured at 200 km (a factor of 1.7 above model predictions and 5.2 above Hedin and Nier of 1965) may be due to lateral transport toward the polar region above the turbopause level as suggested by Johnson (1967).[13]

Atomic Oxygen

The atomic oxygen, number densities are lower than the predicted model densities, densities obtained by Hedin and Nier (1965), and by Hall et. al. The absolute value of the O concentration is lower than the model by a factor of 4 at the lowest altitude while the agreement with the Nier (1965) at low altitudes

is within 16%. Hall, et. al. (1966) show a higher density by a decade at these altitudes (170-220 km). The general shape of the O profile approaches the scale height of the O model above 350 km and the scale height of the O_2 model below 350 km. Comparisons with the Explorer 32 atomic oxygen data[6] indicate good agreement in the 300 to 400 km region. The O/O_2 ratio obtained was 10 at 210 km which agrees well with the model atmosphere predictions.

We believe that the ambient atomic oxygen number densities presented here are lower limits in this altitude range from 174 to 533 km, because the recombination coefficients measured in the laboratory are not consistent with the flight data acquired at high altitudes. This leads to uncertainties concerning adsorption and other surface effects but corrections for these loss processes are not included in the number density calculations.

It is not clear at this time if the profile for atomic oxygen is the result of a time dependent gas-surface interaction or indicative of the actual O profile. (It should be noted that if the profile is the result of surface adsorption causing a decrease in the measured O density with decreasing altitude, this means an increasing adsorption with time; this behavior itself would be unexpected.)

Molecular Oxygen

The molecular oxygen measurements are also lower than model prediction and other comparison data, differing from the model densities by a factor of 10 at 270 km and a factor of 3.5 at the lower altitudes. Hedin and Nier data show a lower absolute density by a factor of 2.6 over the same altitude ranges.

The lower measured oxygen densities are reflected in the calculation of the total mass density from this flight. The model predicts a higher mass density than the Geoprobe measurements over the altitude range of 175 to 285 by a factor of 2.3 to 3.2.

Other Results

Equal densities of O and N_2 (1.52×10^8 cm^{-3}) were measured at 265 km. A ratio of 1 for He/N_2 was obtained at 300 km where the number density value measured was 5.5×10^6 cm^{-3}.

The neutral thermosphere temperature deduced from the Geoprobe N_2 data agrees well with the Thermosphere Probe (NASA 6.06) results obtained under similar solar and geomagnetic conditions, but are lower than the CIRA 1965 Model #2 (1300 hrs) which predicts a higher exospheric temperature (1063°K).

Conclusions

1. The measured N_2 and He densities agree well with the theoretical models above 250 km, while the model values of O and O_2 densities in the lower thermosphere are higher than the Geoprobe measured values.

2. The neutral gas temperature between 133 and 290 km indicates an exospheric temperature of 900°K during the flight. This scale height temperature is 15% lower than the temperature predicted by the appropriate CIRA 1965 model (based on solar flux magnetic conditions and local time), a result consistent with other recent determinations of daytime atmospheric temperature by direct measurement.

3. The measured total density is lower than the model prediction, since the oxygen densities measured were lower than model values.

4. The Geoprobe data result from the first atomic oxygen measurements obtained in the upper atmosphere with a mass spectrometer utilizing intentional recombination within an enclosed, orificed ion source. This technique appears to be feasible where the molecular oxygen concentration is not significant; better laboratory data must be obtained, however, before the technique can be applied with absolute confidence. The O densities measured by the Geoprobe are considered lower limits to the true ambient abundance.

5. Helium measurements on this flight when compared with measurements from other flights indicate the extreme variability of the number density of this gas in the lower thermosphere, and that helium is not completely in diffusive equilibrium below about 180 to 200 km. The variability in density may be caused by variations in the altitude where diffusion becomes dominant over mixing and/or lateral transport above the turbopause toward the polar region, as suggested by Johnson (1967).[13]

6. The Geoprobe N_2 concentration when compared to the measurements on other flights are consistent with theoretical model atmospheric response to solar and magnetic field variations. These consistencies are more pronounced for N_2 than other gases studied due to the relative lack of gas-furface effect on interpretation of flight data and good signal-to-noise over a large altitude interval.

ACKNOWLEDGMENTS

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TABLE 3

Number Density (number/cm) from NASA 8.25

Altitude (km)	N_2	Altitude (km)	He
133	7.58×10^{10}	140	9.41×10^{7}
135	6.38×10^{10}	143	6.93×10^{7}
185	3.14×10^{9}	218	9.83×10^{6}
187	2.87×10^{9}	220	9.35×10^{6}
208	1.16×10^{9}	291	5.76×10^{6}
211	1.01×10^{9}	292	5.75×10^{6}
212	1.11×10^{9}	386	4.15×10^{6}
214	9.75×10^{8}	387	3.89×10^{6}
261	1.86×10^{8}	440	3.27×10^{6}
263	1.82×10^{8}		
279	1.12×10^{8}		
281	9.74×10^{7}		
284	9.05×10^{7}		
287	6.72×10^{7}		
Altitude (km)	O	Altitude (km)	O_2
174	1.12×10^{9}	174	2.82×10^{8}
195	5.30×10^{8}	195	8.3×10^{7}
247	2.10×10^{8}	247	6.67×10^{6}
268	1.71×10^{8}	268	2.25×10^{6}
348	5.79×10^{7}		
368	5.06×10^{7}		
407	3.58×10^{7}		
423	3.10×10^{7}		
458	2.15×10^{7}		
523	9.16×10^{6}		
533	7.56×10^{6}		

TABLE 4

Mass Density and Mean Molecular Weight

Mass Density	Mean Mol. Weight
7.23×10^{-15} @ 284 km	20.99 @ 284
1.25×10^{-14} @ 261 km	22,54 @ 261
5.46×10^{-14} @ 211 km	25.75 @ 211
1.63×10^{-13} @ 185 km	27.03 @ 185
2.36×10^{-13} @ 176 km	27.16 @ 176

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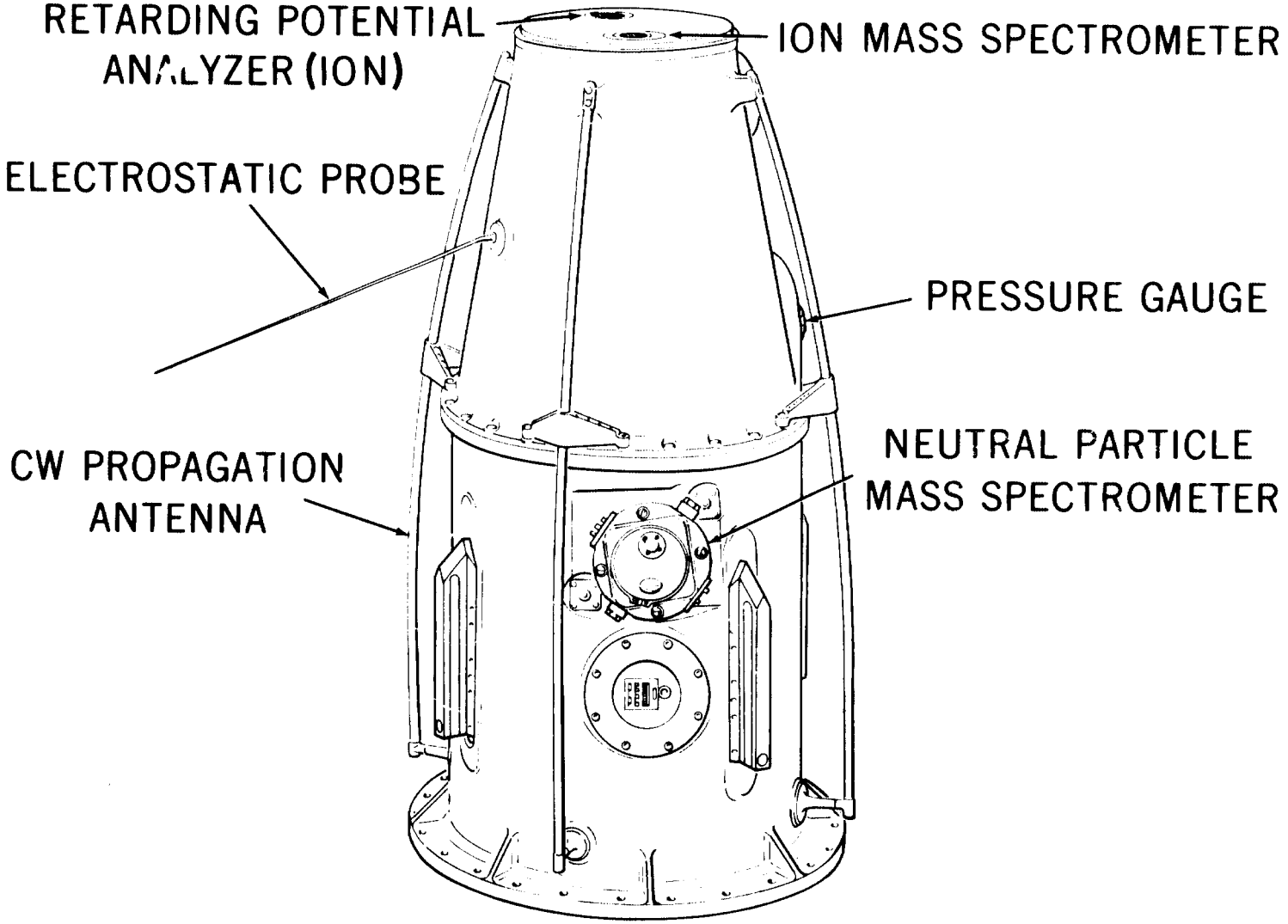

Figure 1–Sketch of the Geoprobe (NASA 8.25) scientific payload showing the location of the neutral particle mass spectrometer.

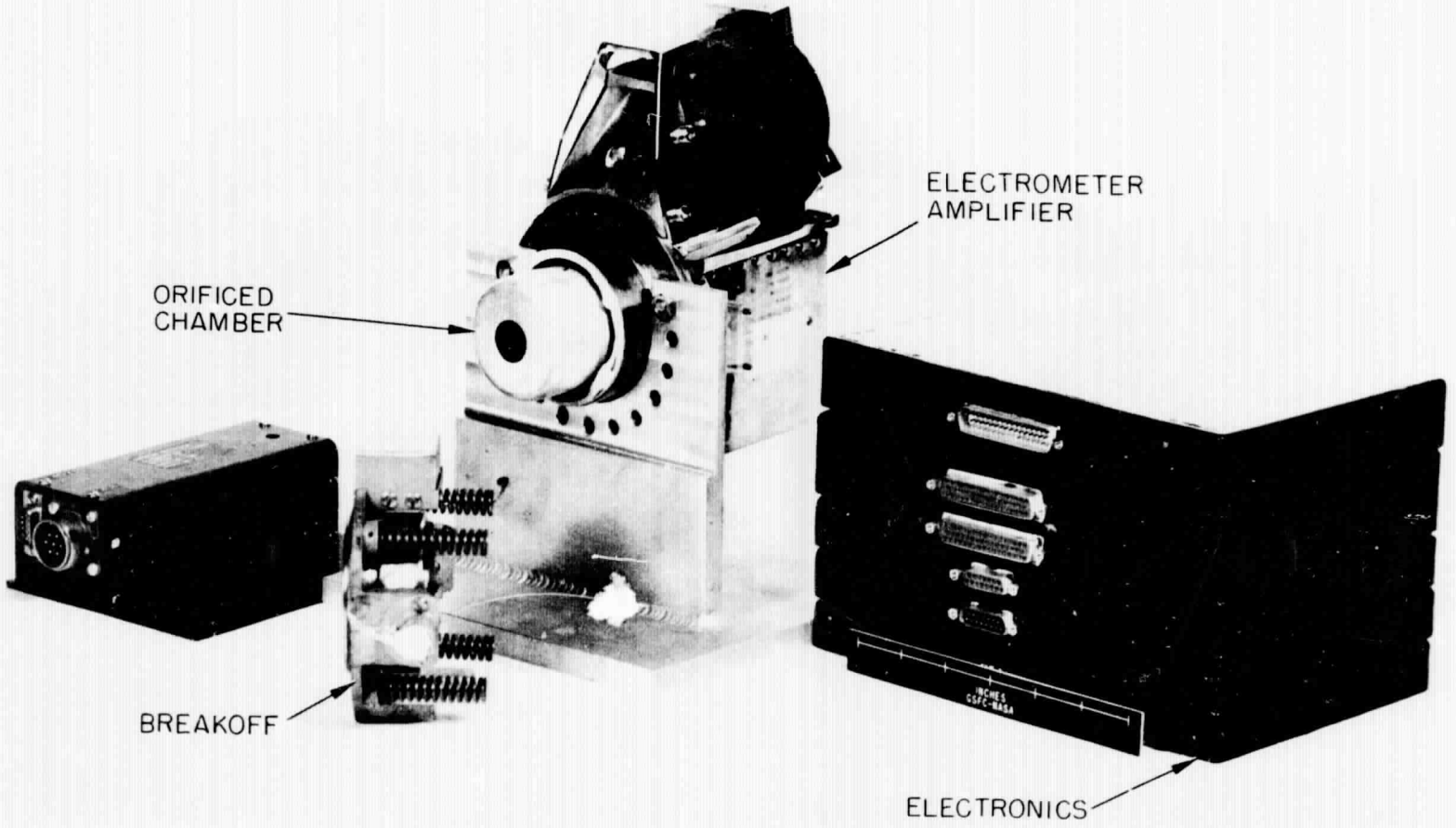

Figure 2–Photograph of the mass spectrometer system.

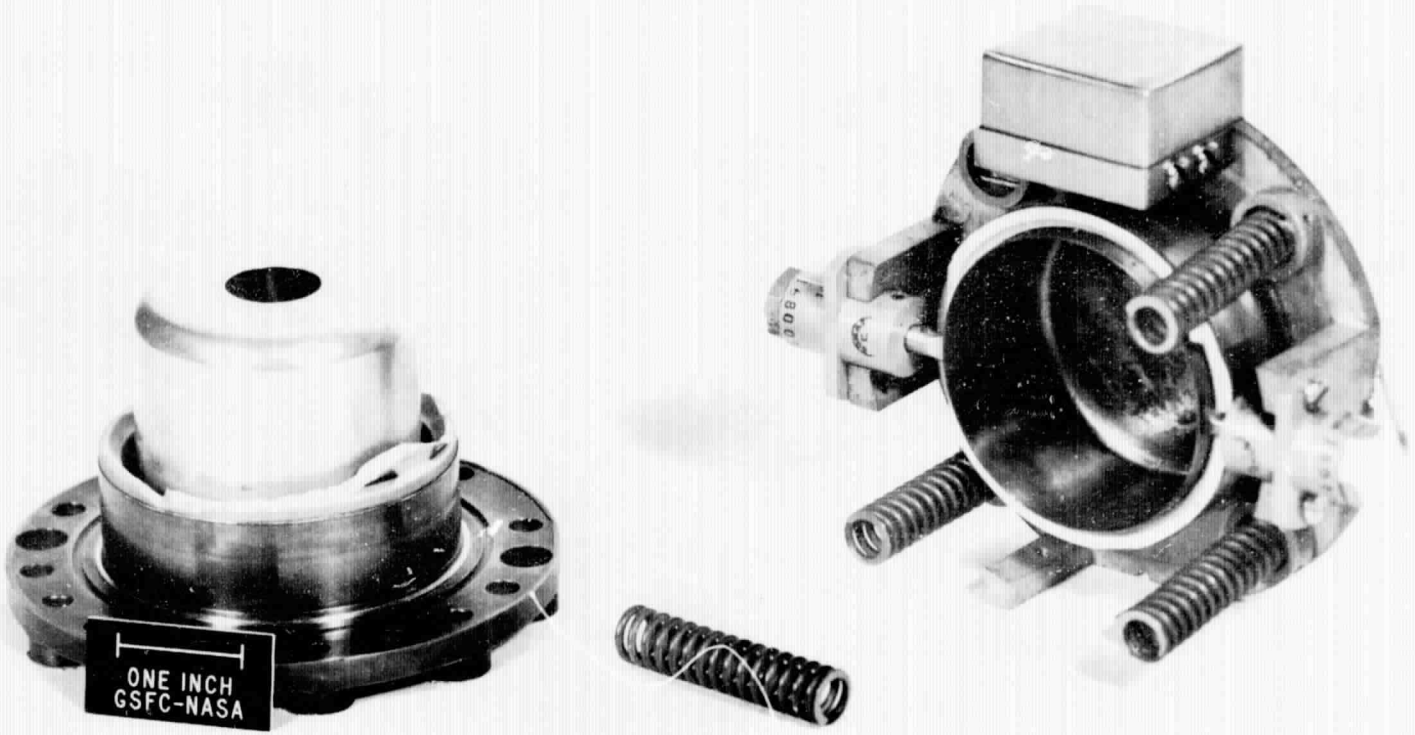

Figure 3–Photograph of the mass spectrometer breakoff device.

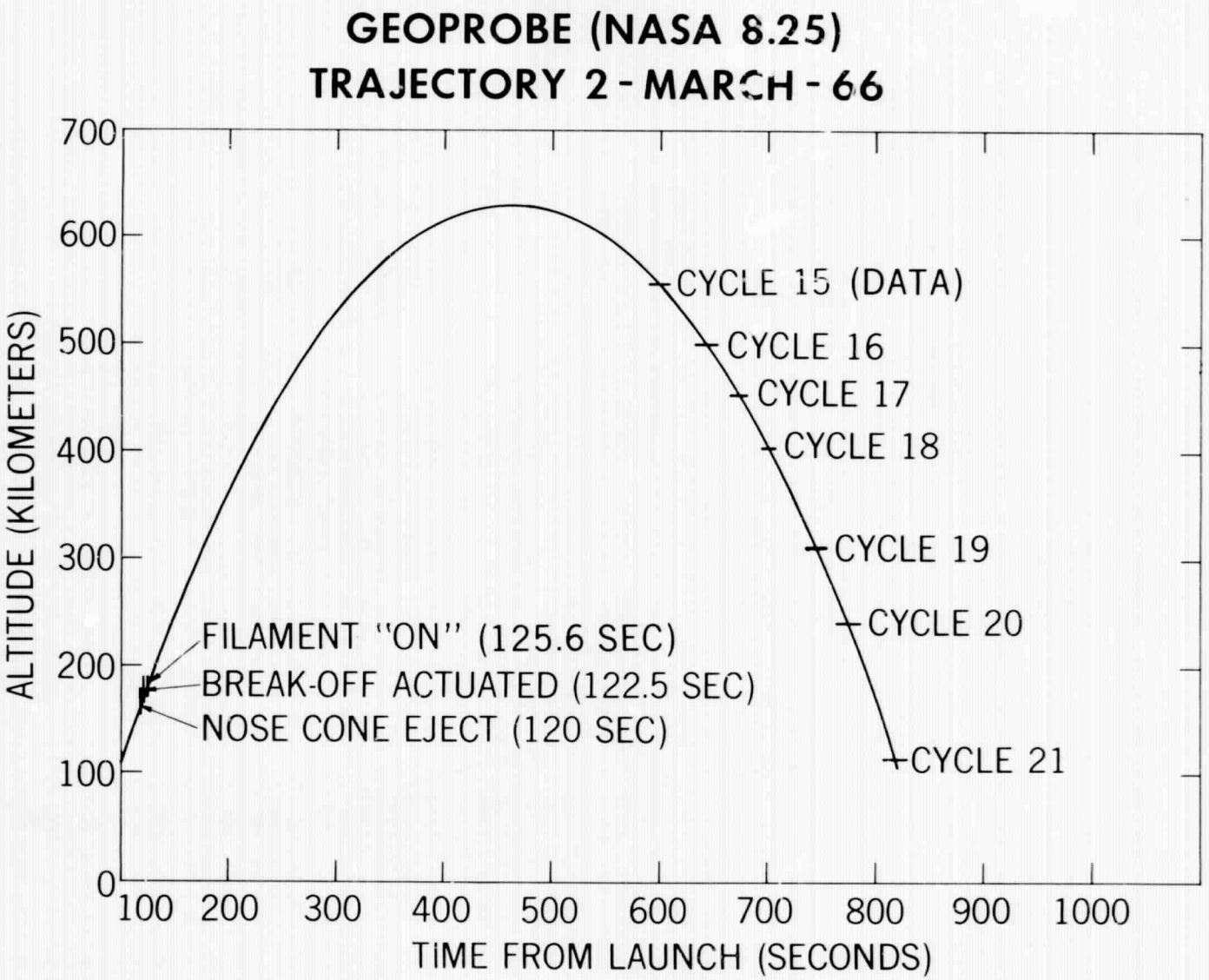

Figure 4–NASA 8.25 trajectory showing the region of useful data.

GEOPROBE MASS SPECTROMETER

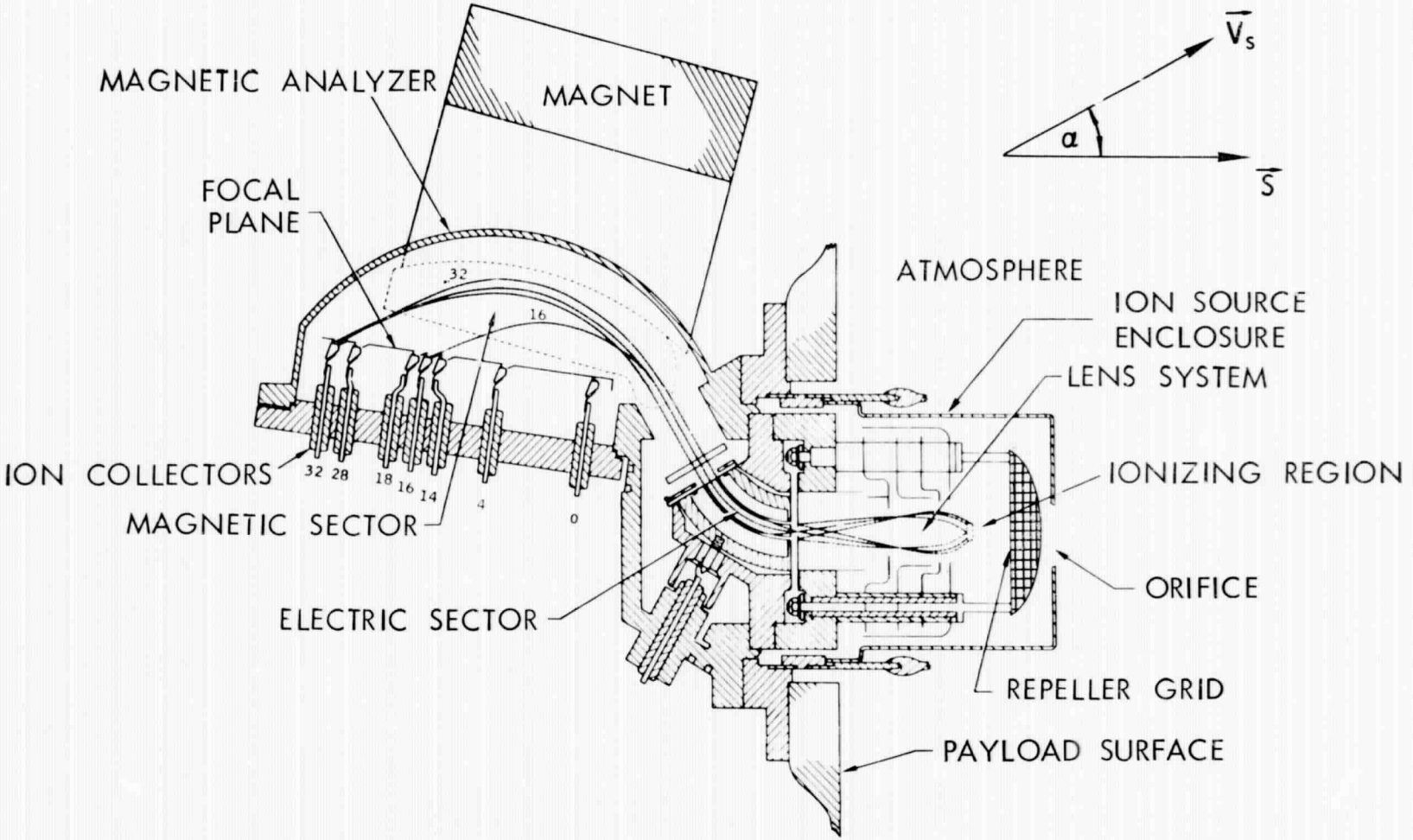

Figure 5–Photograph of the Geoprobe mass spectrometer instrument.

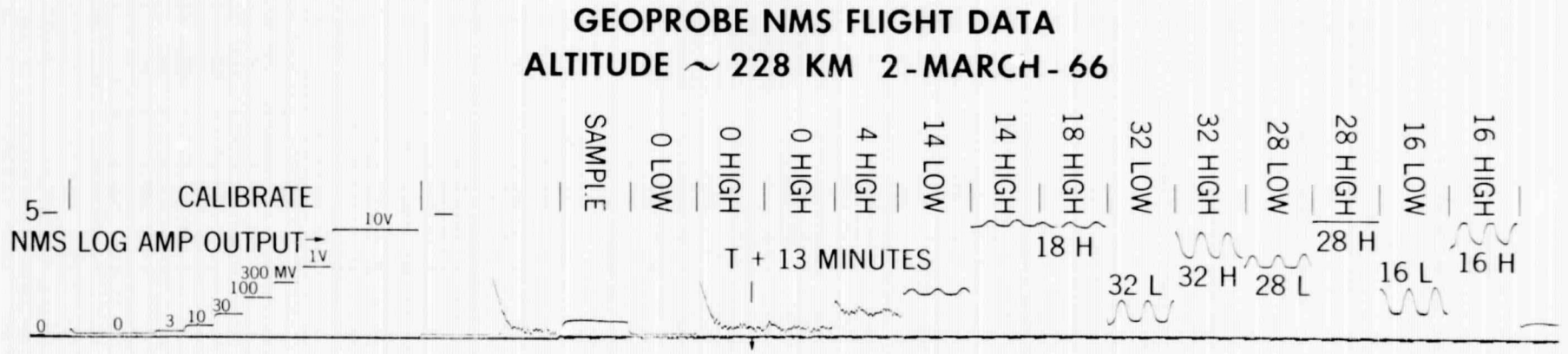

Figure 6–Photograph of the NMS flight data showing the pressure variations during the payload spin cycle.

CALIBRATION SYSTEM

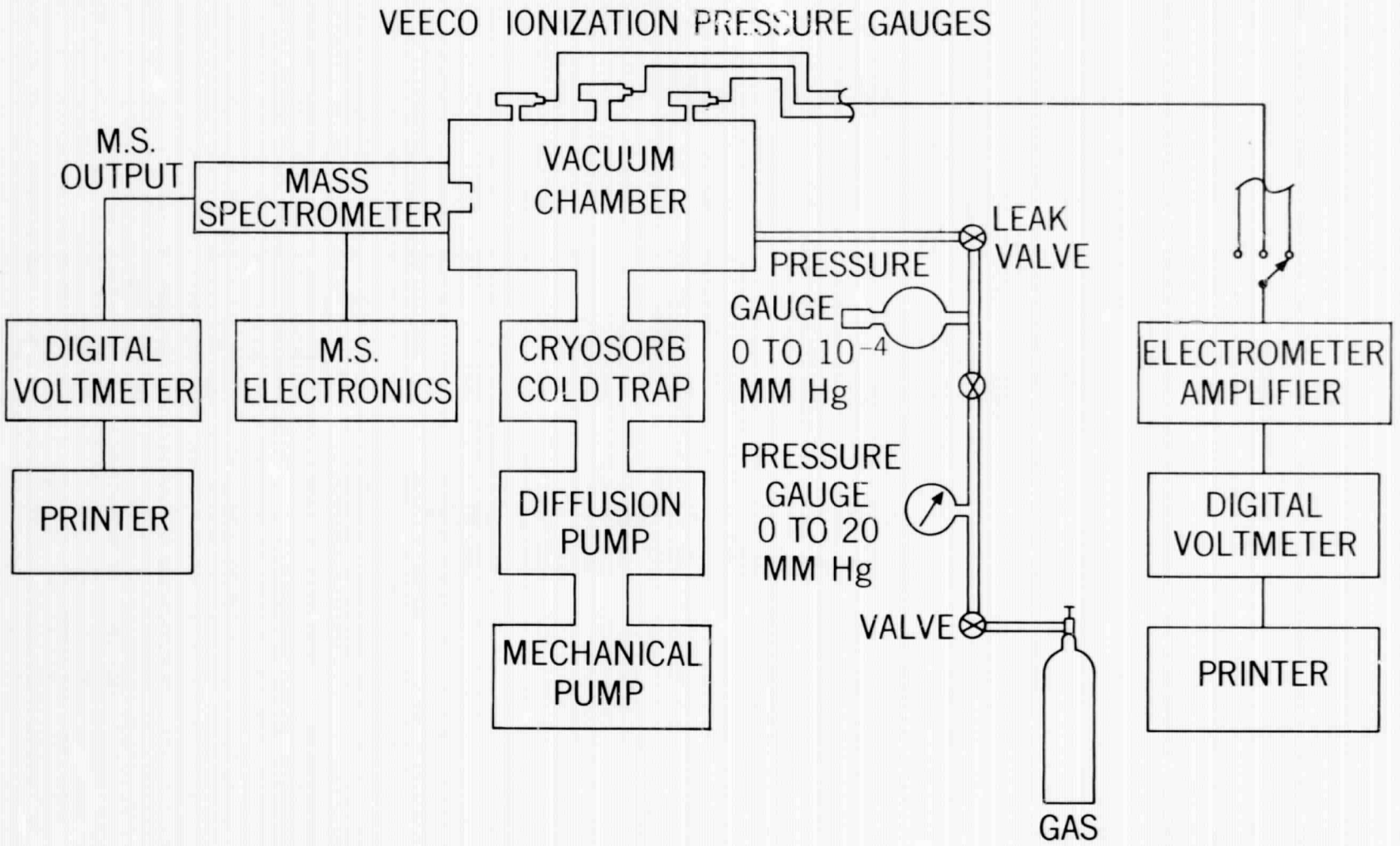

Figure 7–Block diagram of the NMS calibration system.

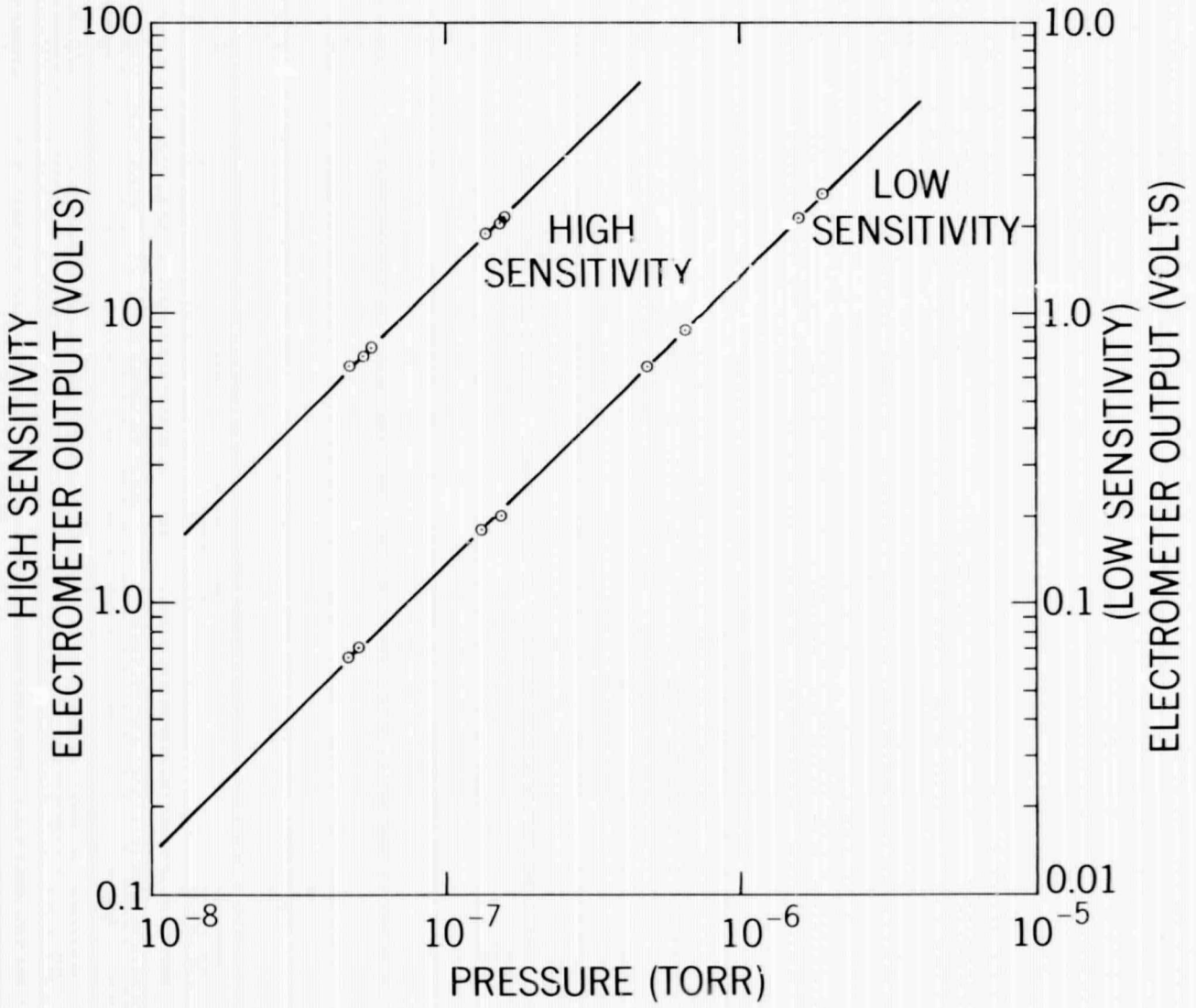

Figure 8–NMS electrometer output vs. pressure for N_2.

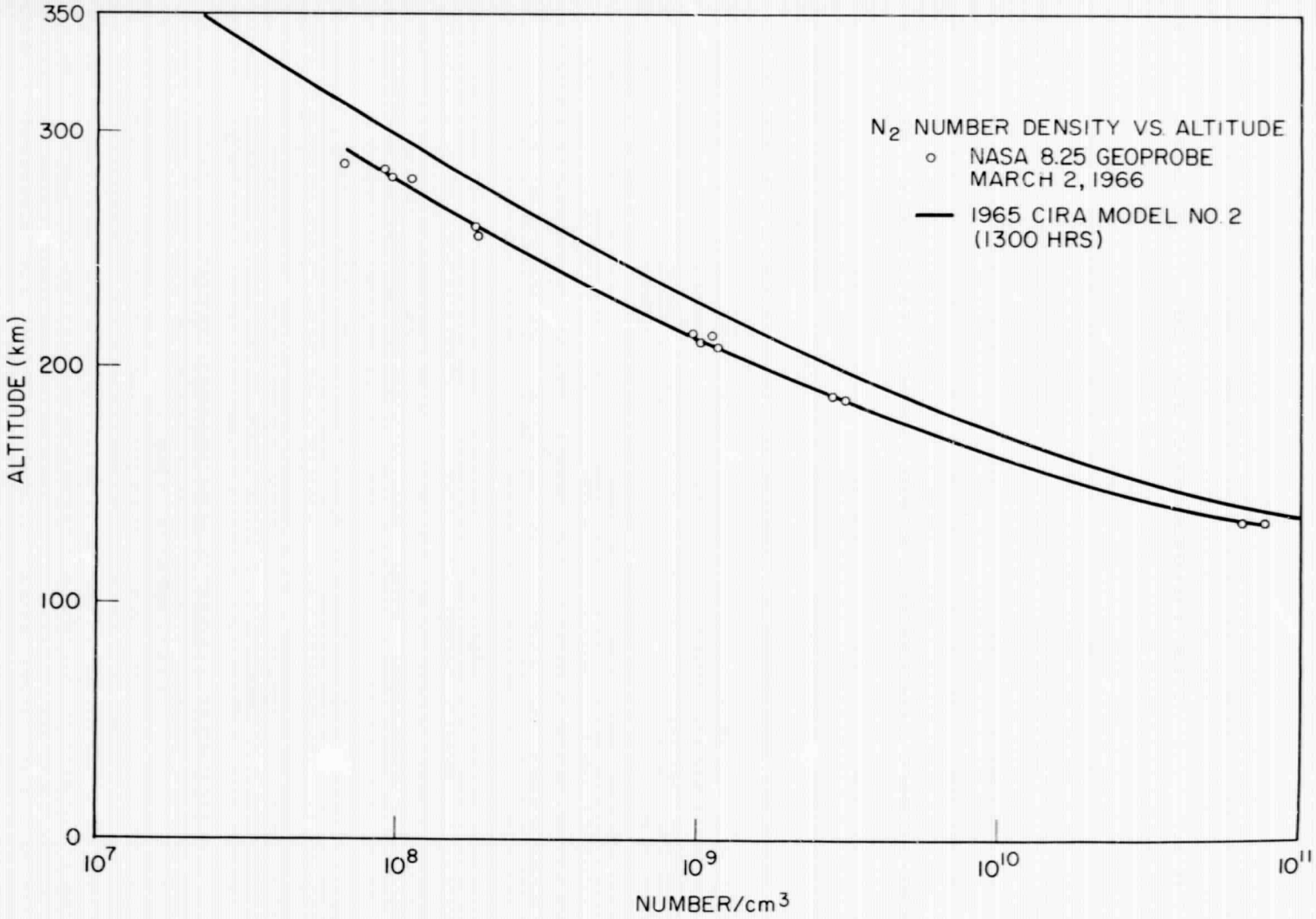

Figure 9–Molecular nitrogen number density vs. altitude along with the 1965 CIRA Model No. 2 @ 1300 hrs.

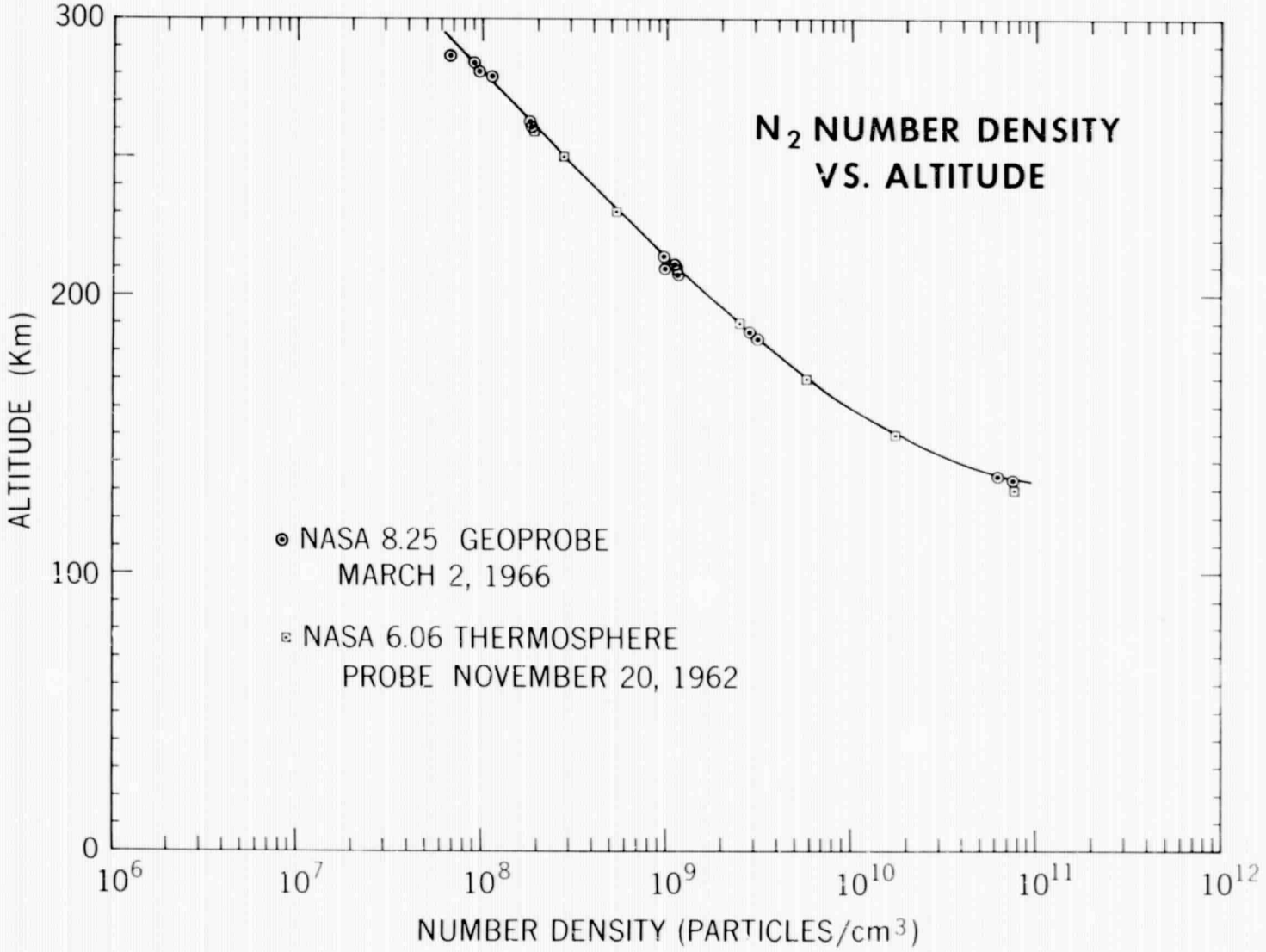

Figure 10–N_2 number density vs. altitude with NASA 6.06 comparisons.

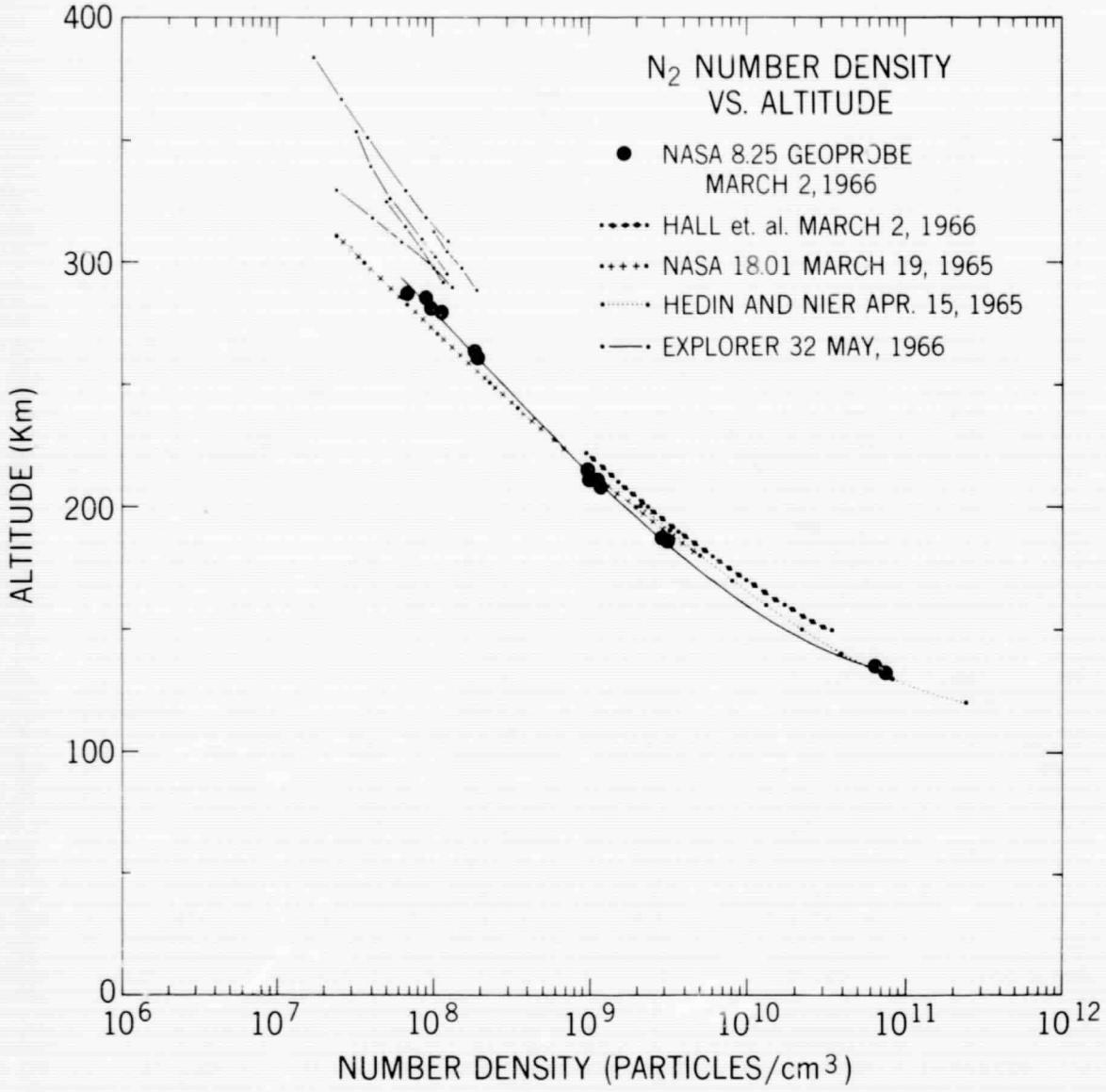

Figure 11–N_2 number density vs. altitude with Hall et. al., NASA 18.01, Hedin and Nier, and Explorer 32 comparisons.

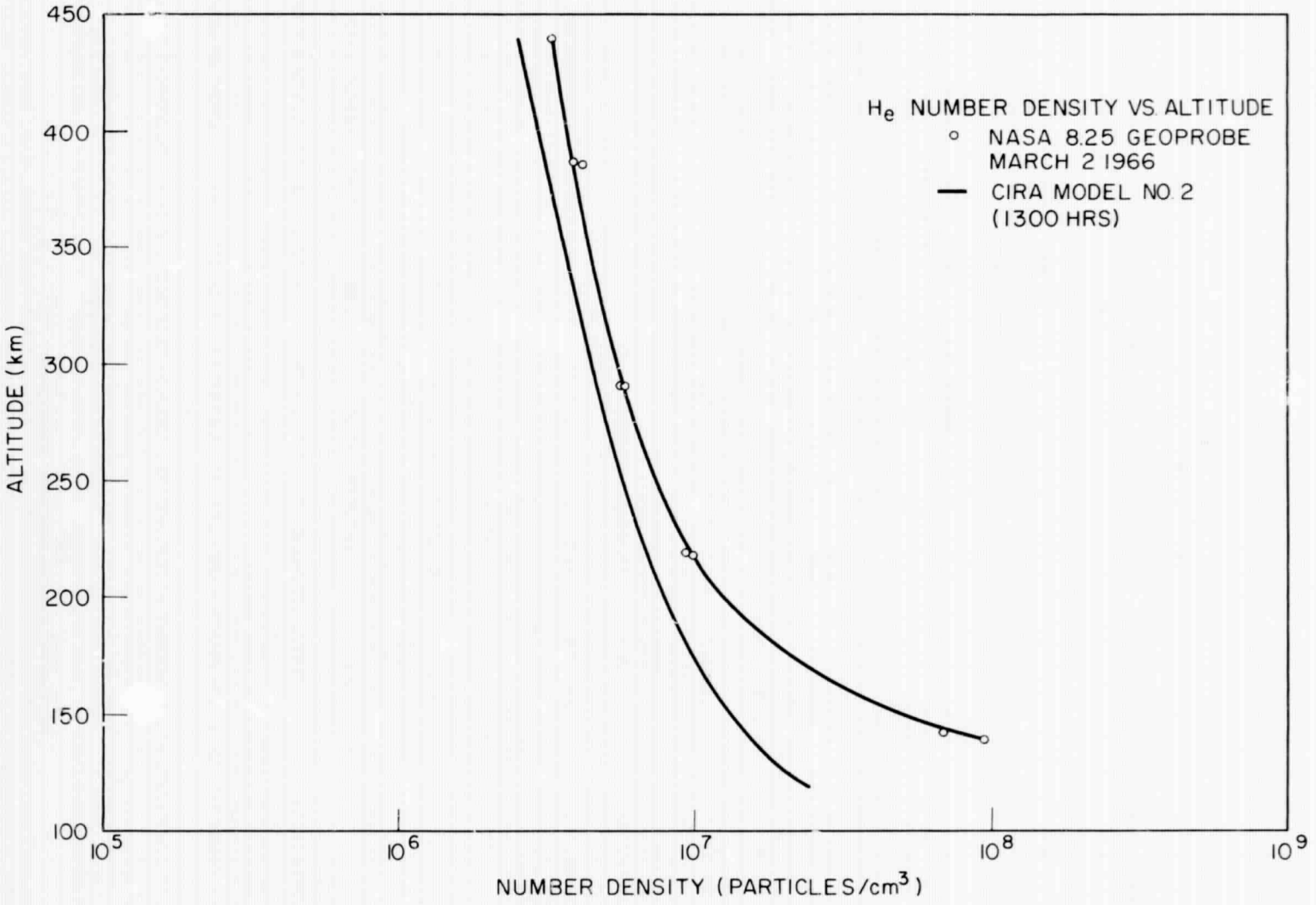

Figure 12–Helium number density vs. altitude with the CIRA Model No. 2 @ 1300 hrs.

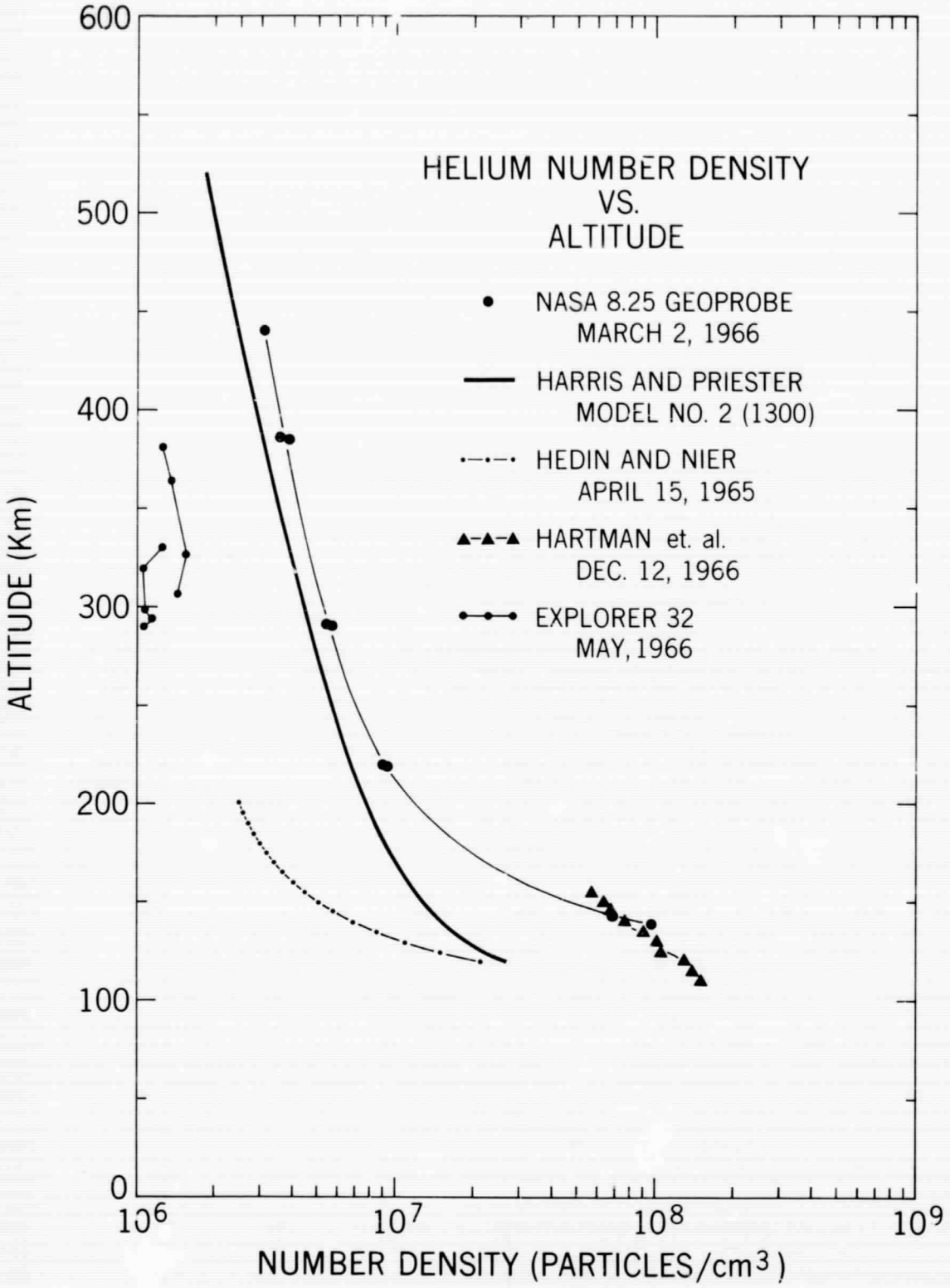

Figure 13–Helium number density vs. altitude with Hedin and Nier, Hartman, et. al., and Explorer 32 comparisons.

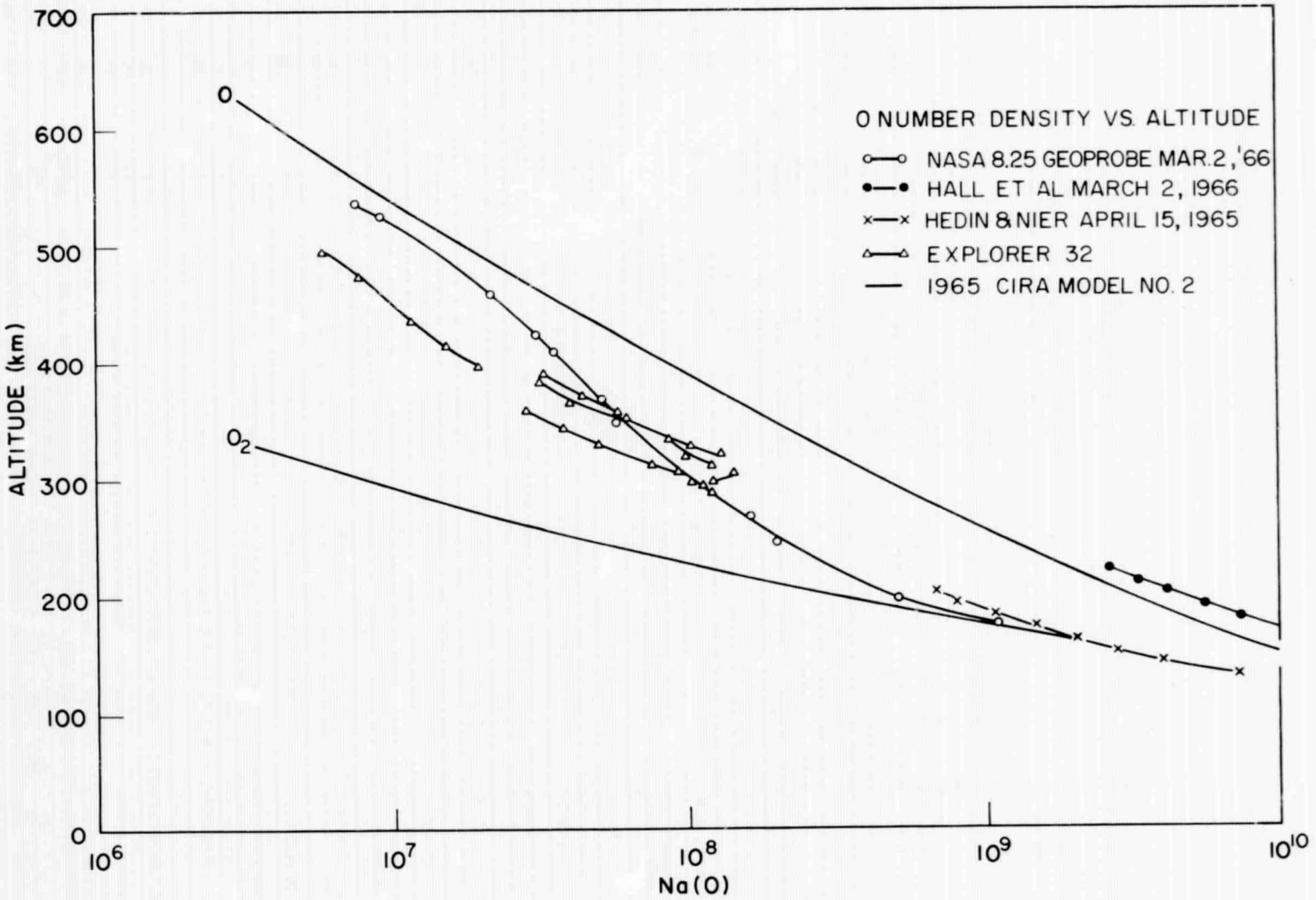

Figure 14–Atomic oxygen number density vs. altitude with CIRA 1965 models, Hall et al., Hedin and Nier, and Explorer 32 comparisons.

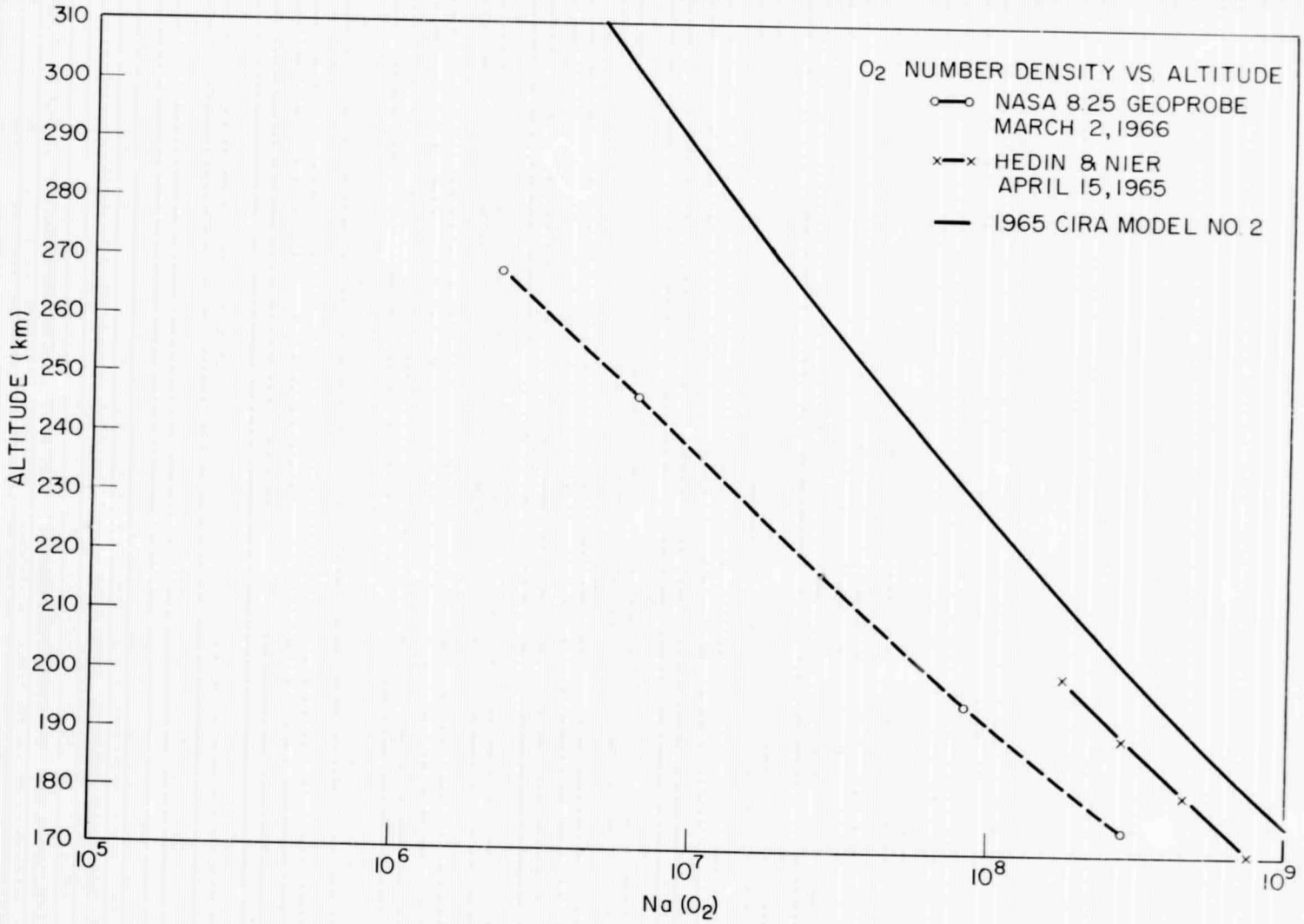

Figure 15–Molecular oxygen number density vs. altitude with CIRA 1965 model, and Hedin and Nier comparison.

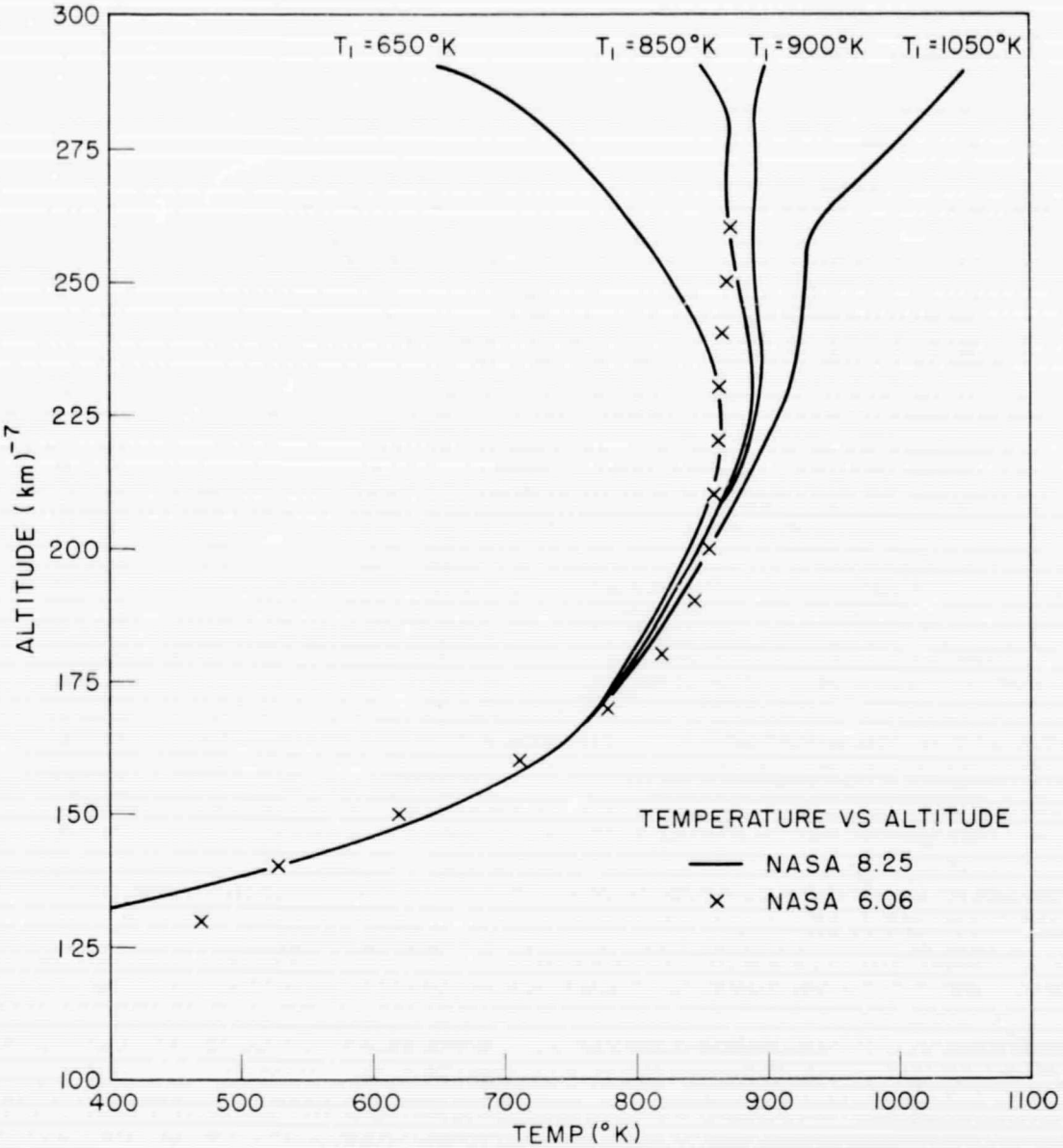

Figure 16–Neutral thermosphere temperature obtained from NMS using N_2 profile. NASA 6.06 also shown for comparison.

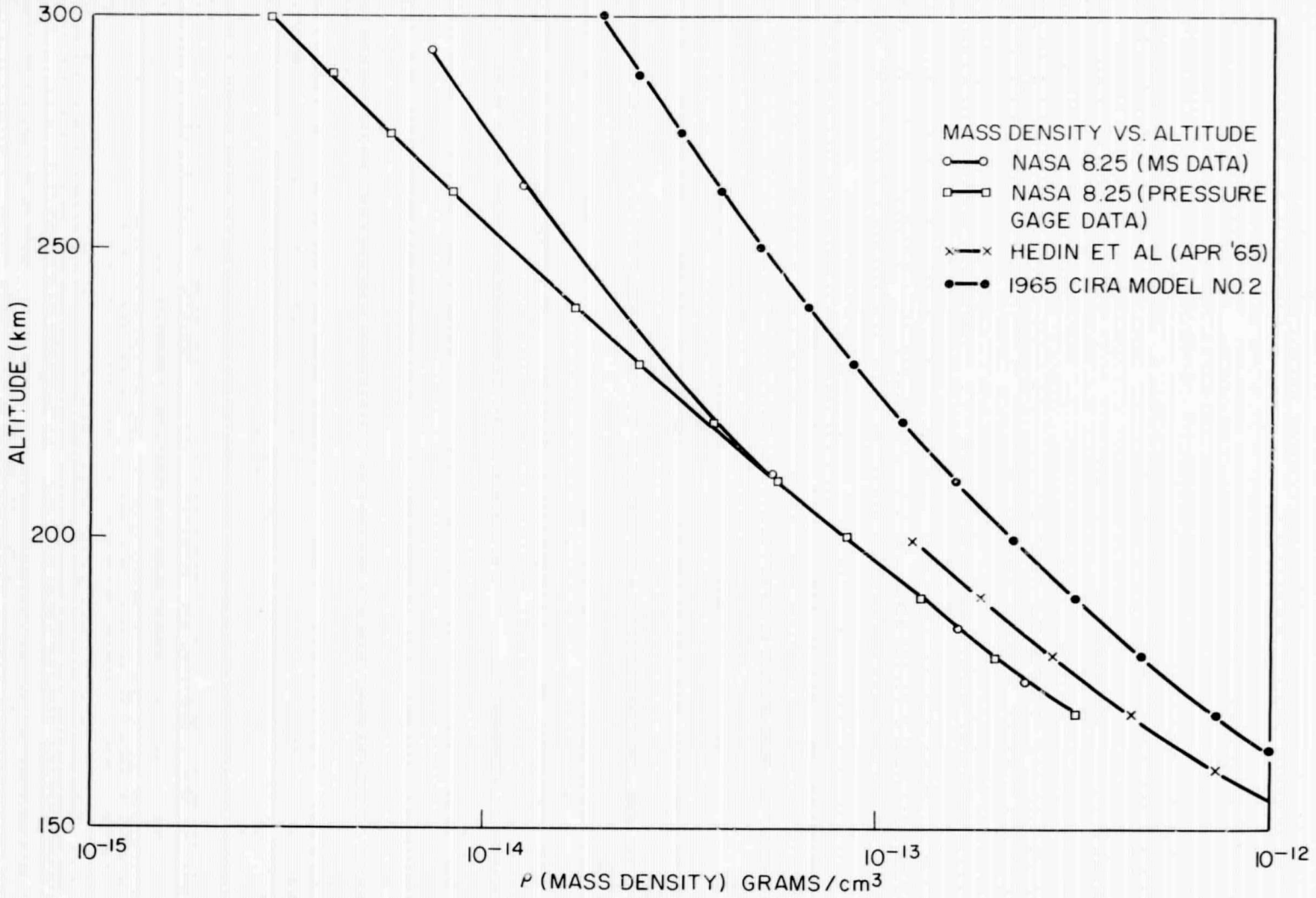

Figure 17–Mass density vs. altitude.

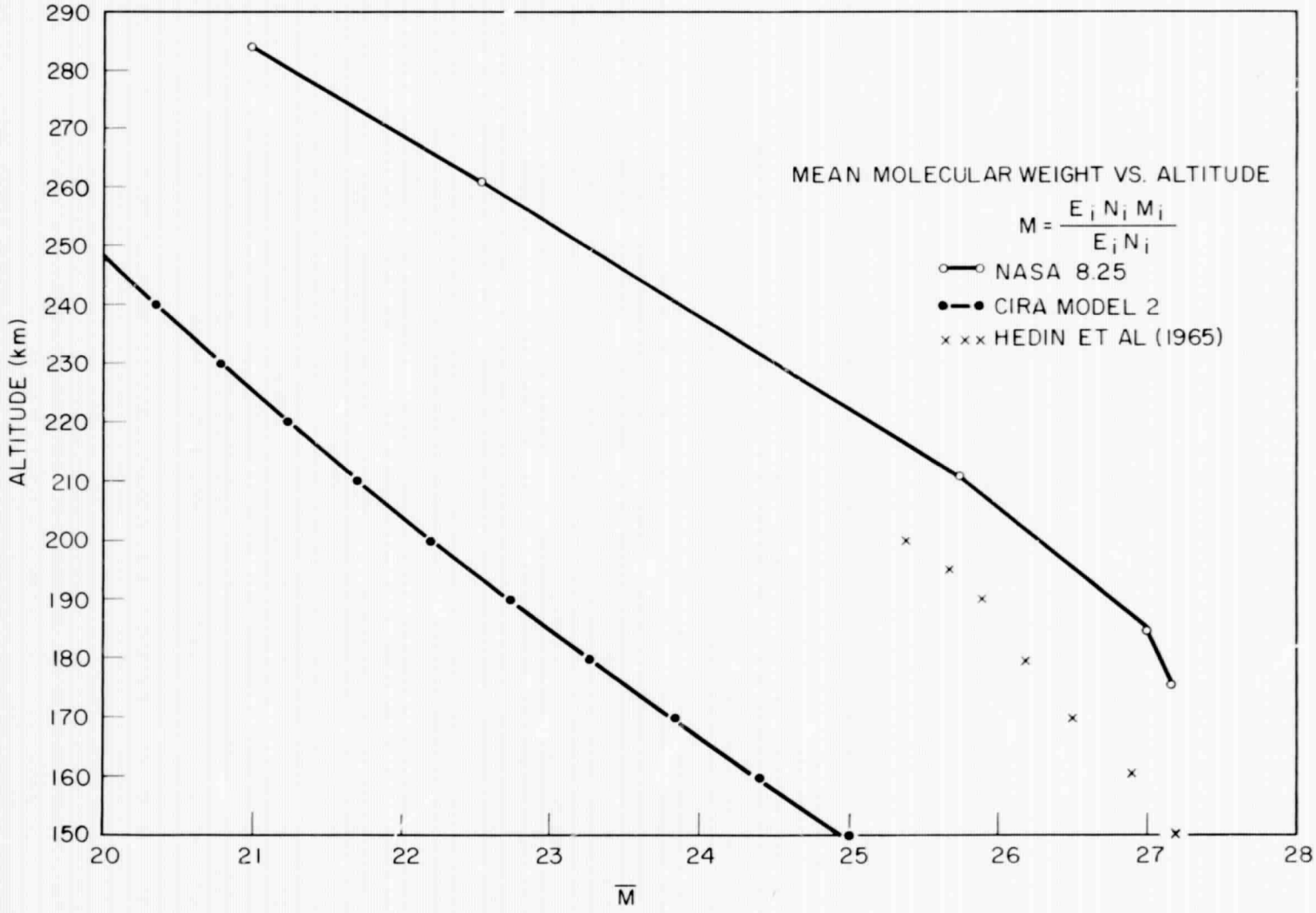

Figure 18–Mean molecular weight vs. altitude.